

## Description

High-Pressure Discharge Lamp Lighting Device and Lighting  
Fixture

Technical Field

5 [0001] This invention relates to a high-pressure  
discharge lamp lighting device and a lighting fixture using  
it.

Background Art

[0002] JP-A-2003-223997 proposes a high-pressure  
10 discharge lamp lighting device having a capability of deep  
dimming. FIG. 22 shows change rate of lamp power to voltage  
across lamp V1a. Circuit operates at the intersection point  
of the output characteristic of a lighting device indicated  
by a dotted line a, b in the figure and the lamp characteristic  
15 indicated by a heavy solid line c. If the circuit is thus  
operated, a constant-voltage characteristic can be taken in  
a comparatively high output dimming range (for example, 40%  
to 100%) until the voltage across lamp V1a turns to rise as  
shown in a in FIG. 22, and roughly constant power can be obtained  
20 for fluctuation of lamp impedance caused by the individual  
difference and the life of lamp; the circuit operates with a  
constant-current characteristic in a comparatively low output  
dimming range (for example, 40% or less) where the voltage  
across lamp V1a turns to rise as shown in b in FIG. 22, so that  
25 an operation point of an intersection point with the lamp

characteristic can be taken, gong out does not occur, stable lighting can be performed, and the dimming range can be enlarged.

[0003] FIG. 23 shows target values of lamp current  $I_{la}$  in output characteristics a and b in FIG. 22. As described above, the target value of the lamp current  $I_{la}$  is decreased in response to an increase in the voltage across lamp  $V_{la}$  in the dimming area of the output characteristic a, thereby performing rough constant-power control, and the target value of the lamp current  $I_{la}$  is made constant in response to an increase in the voltage across lamp  $V_{la}$  in the dimming area of the output characteristic b, thereby performing constant-current control.

[0004] A discharge lamp lighting device of a characteristic as shown in JP-A-6-111987 is also known for the purpose of widening the dimming range. FIG. 24 shows the characteristic and shows lamp voltage  $V_{la}$  relative to lamp current  $I_{la}$  of the discharge lamp lighting device. Assuming that the current command value at the instant at which the lamp voltage  $V_{la}$  exceeds a threshold value  $V_{th}$  is X, if adjustment is made so as to output a current command value Y or Z lower than X, it crosses voltage-current curve Q of discharge lamp at a y point or a z point and the light state can be still maintained. Thus, when the lamp voltage  $V_{la}$  is lower than the threshold value  $V_{th}$ , constant-power dimming is performed, and

constant-current dimming is performed in the range in which the lamp voltage  $V_{la}$  is equal to or greater than the threshold value  $V_{th}$ . This means that the dimming range is widened to a smaller luminance area.

5 Patent document 1: JP-A-2003-223997

Patent document 2: JP-A-6-111987

Disclosure of the Invention

Problems to be Solved by the Invention

[0005] In the arts in patent documents 1 and 2, the  
10 lighting device is provided with a constant-current characteristic to dim the high-pressure discharge lamp to a low luminous flux level for reliably maintaining the operation point of the output characteristic of the lighting device and the lamp characteristic as compared with dimming control based  
15 on constant power. However, for example, in a deeper dimming area with illuminance ratio 20% or less assuming that the rated lighting time is 100%, the lamp voltage rises rapidly as the dimming becomes deeper as indicated by the heavy solid line c in FIG. 22 and thus it becomes difficult to maintain the  
20 operation point of the lighting device and the lamp characteristic, resulting in occurrence of going out; this is a defect.

[0006] It is therefore an object of the invention to  
provide a high-pressure discharge lamp lighting device capable  
25 of executing dimming up to a lower luminous flux level than

the dimming lower limit obtained by performing constant-current control as described in the related art example.

#### Means For Solving the Problems

5 [0007] To solve the problem described above, according to the invention, there is provided a high-pressure discharge lamp lighting device including a power conversion unit 1 for supplying AC power to a high-pressure discharge lamp DL as a load with a DC power supply E as an input power supply for  
10 performing all lighting or dimming lighting as shown in FIG. 2, wherein in an area where the voltage across the high-pressure discharge lamp DL grows as dimming deepens, the output characteristic of the power conversion unit 1 is a characteristic for increasing the output current of the power  
15 conversion unit 1 in response to an increase in the output voltage of the power conversion unit 1 as shown in characteristic BC1 in FIG. 1 (b).

#### Advantages of the Invention

[0008] According to the invention as claimed in claim 1,  
20 low luminous lighting can be stably executed in a wider range as compared with the constant-current control in the related art.

According to the invention as claimed in claim 2, change amount of lamp current/change amount of lamp voltage is made  
25 constant, whereby control can be facilitated.

According to the invention as claimed in claim 3, if dimming is deepened, the operation point is provided reliably, so that low luminous lighting can be stably executed in a wider range.

5           According to the invention as claimed in claim 4, after start, the output characteristic of the lighting device is provided from lamp voltage 0 V to the voltage at the operation point, so that low luminous dimming starting can be executed reliably, for example.

10           According to the invention as claimed in claim 5, the value of the lamp voltage at the switch point between constant-current control and the operation according to the invention is changed in response to dimming, so that brightness adjustment in a low luminous area can be made easily.

15   [0009]       According to the invention as claimed in claim 6, the lamp power in the vicinity of the dimming lower limit can be set to power at the same degree as that at the initial time for variation of the lamp with time.

          According to the invention as claimed in claim 7, smooth  
20 and continuous control can be executed in a wide range of the rated lighting to the dimming lower limit using the constant-power control, the intermediate control of the constant-power control and the constant-current control, the constant-current control, and the low luminous lighting time  
25 control of the invention in combination.

According to the invention as claimed in claim 8, 9, 10, control can be facilitated and can be realized by a simple control circuit.

According to the invention as claimed in claim 11, the  
5 data table of the microcontroller is referenced, whereby the control operation switching circuit responsive to the lamp voltage, etc., becomes unnecessary and the circuit can be simplified.

According to the invention as claimed in claim 12, the  
10 amount of data to be stored in the data table of the microcontroller can be lessened.

According to the invention as claimed in claim 13, a lighting fixture that can be dimmed up to a lower level than that in the related arts can be provided.

#### 15 Brief Description of the Drawings

[0010] FIG. 1 is a characteristic drawing to show the operation of a first embodiment of the invention.

FIG. 2 is a circuit diagram to show a circuit configuration example of the first embodiment of the invention.

20 FIG. 3 is a circuit diagram to show a specific circuit configuration example of the first embodiment of the invention.

FIG. 4 is a characteristic drawing to show measurement data provided when dimming control of a high-pressure discharge lamp is performed using low luminous lighting control of the

25 invention.

FIG. 5 is a characteristic drawing to show measurement data provided when dimming control of a high-pressure discharge lamp is performed using constant-current control in a related art.

FIG. 6 is a characteristic drawing to show the operation of  
5 a second embodiment of the invention.

FIG. 7 is a characteristic drawing to show the operation of a third embodiment of the invention.

FIG. 8 is a circuit diagram to show a circuit configuration example of the third embodiment of the invention.

10 FIG. 9 is a characteristic drawing to show the operation of a fourth embodiment of the invention.

FIG. 10 is a circuit diagram to show a circuit configuration example of the fourth embodiment of the invention.

FIG. 11 is a circuit diagram to show another circuit  
15 configuration example of the fourth embodiment of the invention.

FIG. 12 is a characteristic drawing to show the operation of a fifth embodiment of the invention.

FIG. 13 is a circuit diagram to show a circuit configuration  
20 example of the fifth embodiment of the invention.

FIG. 14 is a characteristic drawing to show the operation of a sixth embodiment of the invention.

FIG. 15 is a characteristic drawing to show the operation of the sixth embodiment of the invention.

25 FIG. 16 is a characteristic drawing to show the operation of

the sixth embodiment of the invention.

FIG. 17 is a circuit diagram to show a circuit configuration example of the sixth embodiment of the invention.

FIG. 18 is a circuit diagram to show another example of a  
5 specific circuit of a lighting device of the invention.

FIG. 19 is a circuit diagram to show still another example of the specific circuit of the lighting device of the invention.

FIG. 20 is a circuit diagram to show a different example of the specific circuit of the lighting device of the invention.

10 FIG. 21 is a perspective view to show an example of the appearance of a lighting fixture using the lighting device of the invention.

FIG. 22 is a characteristic drawing of a first related art example.

15 FIG. 23 is an operation schematic representation of the first related art example.

FIG. 24 is a characteristic drawing of a second related art example.

#### Description of Reference Numerals

20 [0011] E DC power supply

1 Power conversion unit

2 Dimmer

3 DC/DC conversion unit

4 DC/AC conversion unit

25 5 Control circuit



DL High-pressure discharge lamp

Best Mode for Carrying out the Invention

[0012] (First embodiment)

FIGS. 1 (a) and (b) show the operation characteristics  
5 of a discharge lamp lighting device according to a first  
embodiment of the invention; FIG. 1 (a) shows the output  
characteristic of a lighting device and lamp characteristic  
on a graph of lamp power  $W$  relative to lamp voltage  $V$ . In the  
figures, a solid line LC shown so as to pass through points  
10 a and b indicates the lamp characteristic and a line BC1 made  
up of a solid line and a dotted line shown so as to pass through  
points A and B indicates the output characteristic of the  
lighting device according to the embodiment. For comparison,  
the output characteristic based on constant-current control  
15 shown in the related art example is indicated by a dotted line  
BC2.

[0013] In the lamp characteristic LC, if dimming is  
deepened from the rated lighting indicated by the point a,  
namely, the lamp power  $W$  is lessened, the lamp voltage  $V$  becomes  
20 roughly constant or a little lowers. If dimming is still  
executed although the lamp voltage reaches one point ( $V_b$ ), the  
lamp voltage rapidly rises after the point b.

[0014] At this time, an intersection point CP of the output  
characteristic BC1 of the lighting device and the lamp  
25 characteristic LC, indicated by a white circle becomes the

operation point of the lamp. The output characteristic of the lighting device is made a characteristic like BC1, whereby the characteristic curves of the lamp characteristic LC and the output characteristic BC1 cross orthogonally and thus the operation point is reliably provided and when dimming is further deepened, it also becomes easy to maintain the operation point. Consequently, it is made possible to stably light up to deep dimming.

[0015] In this connection, in constant-current control as indicated in the related art example, namely, the output characteristic indicated by the dotted line BC2, the lamp also operates at the intersection point CP of the lamp characteristic LC and the output characteristic BC2; since the lamp characteristic LC and the output characteristic BC2 are close to each other in gradient as compared with the operation described above and thus if dimming is further deepened, going out easily occurs.

[0016] FIG. 1 (b) is provided by replacing the characteristics in FIG. 1 (a) with a graph of lamp voltage V and lamp current I and shows those corresponding to the lamp characteristic LC and the output characteristics BC1 and BC2 in FIG. 1 (a). It is also seen in FIG. 1 (b) that the output characteristic BC1 and the lamp characteristic LC cross orthogonally and the operation point is reliably provided. Thus, it is made possible to stably light up to deep dimming.

[0017] If the gradient in the vicinity of the operation point in FIG. 1 (b), namely, (change amount of lamp current I/change amount of lamp voltage V) is roughly constant, circuit design is facilitated.

5 [0018] For the output characteristic BC2 indicating constant-current control, if dimming is further deepened, the characteristic gradient becomes similar to that of the lamp characteristic LC and thus the operation point becomes unstable and going out easily occurs.

10 [0019] FIG. 2 shows the circuit configuration of the lighting device according to the embodiment. The lighting device is made up of a DC power supply E, a power conversion unit 1, a high-pressure discharge lamp DL connected to the power conversion unit 1, and a dimmer 2 for transmitting a dimming  
15 signal to the power conversion unit 1.

[0020] The power conversion unit 1 includes a DC/DC conversion unit 3 connected to both ends of the DC power supply E, a DC/AC conversion unit 4 connected to output of the DC/DC conversion unit 3, and a control circuit 5 for performing on/off  
20 control of a switching element Q of the DC/DC conversion unit 3.

[0021] The control circuit 5 is made up of a lamp current detection circuit 51 for detecting a current flowing into the high-pressure discharge lamp DL and outputting a current lamp  
25 current value I<sub>la</sub>, a lamp current command value computation

circuit 52 for receiving a signal from the dimmer 2 and computing a lamp current command value  $I_{la}^*$ , and a gain circuit 53 for multiplying the difference between the lamp current command value  $I_{la}^*$  and the detection value  $I_{la}$  by  $\alpha$ , and operates so that the lamp current command value  $I_{la}^*$  and the detection value  $I_{la}$  roughly match by turning on/off the switching element Q of the DC/DC conversion unit 3 based on the pulse width responsive to the output of the gain circuit 53.

[0022] FIG. 3 is a circuit diagram to show the configuration in FIG. 2 in more detail. The DC power supply E is made up of an AC power supply  $V_s$ , a diode bridge DB made up of diodes D1, D2, D3, and D4, a step-up chopper circuit made up of an inductance L1, a switching element Q1, a diode D5, and an electrolytic capacitor C1, and a control circuit 6 of the step-up chopper circuit. The control circuit 6 detects the voltage of the electrolytic capacitor C1 and controls turning on/off of a switching element Q1.

[0023] The DC/DC conversion unit 3 is a step-down chopper circuit made up of a switching element Q2, a diode D6, an inductance L2, and a capacitor C2, and a resistor R0 for detecting lamp current is inserted in series to the ground side of the output end of the step-down chopper. The control circuit 5 adjusts turning on/off of the switching element Q2, whereby the DC/AC conversion unit 4 at the following stage can control

the value of the lamp current supplied to the high-pressure discharge lamp DL.

[0024]        The DC/AC conversion unit 4 is implemented as an inverter of full bridge type wherein a series circuit of switching elements Q3 and Q4 and a series circuit of switching elements Q5 and Q6 are connected in parallel and a series circuit of an igniter IG for starting the high-pressure discharge lamp DL and the high-pressure discharge lamp DL is connected between the connection point of the switching elements Q3 and Q4 and the connection point of the switching elements Q5 and Q6. The switching elements Q3, Q4, Q5, and Q6 are turned on/off according to a signal output through a drive circuit 72 from a low-frequency oscillator 71 of a control circuit 7, and a state in which the switching elements Q3 and Q6 are on and the switching elements Q4 and Q5 are off and a state in which the switching elements Q3 and Q6 are off and the switching elements Q4 and Q5 are on are repeated alternately at a frequency of about several 100 Hz. Thus, a current IDL flowing into the high-pressure discharge lamp DL becomes a rectangular wave at about several 100 Hz.

[0025]        The control circuit 5 is made up of the lamp current command value computation circuit 52 for receiving a signal from the dimmer 2 and outputting a lamp current command value Ila\*, an operational amplifier OP1 having a plus terminal to which the lamp current command value Ila\* is input, and a drive

circuit 54 for controlling turning on/off of the switching element Q2 based on the pulse width responsive to the output level of the operational amplifier OP1. A signal of the lamp current I<sub>la</sub> detected from one end of the resistor R0 provided  
5 in the DC/DC conversion unit 3 is input through a resistor R1 to a minus terminal of the operational amplifier OP1, a resistor R2 is connected between the minus terminal and an output terminal of the operational amplifier OP1, and the operational amplifier OP1 performs feedback operation so that the lamp  
10 current command value I<sub>la</sub>\* matches the command value I<sub>la</sub>\*.

[0026] The lamp current command value computation circuit 52 adopts the sum of DC voltage source V\* varied by the dimmer 2 and detection voltage V<sub>la</sub> provided by dividing the voltage of the output end of the DC/DC conversion unit 3, namely, the  
15 lamp voltage of the high-pressure discharge lamp DL through resistors R3 and R4 as the lamp current command value I<sub>la</sub>\*. For averaging, a capacitor C3 is connected in parallel with the resistor R4. If the resistors R3 and R4 and the capacitor C3 do not exist in the circuit, the output voltage of the DC  
20 voltage source V\* adjusted by the dimmer 2 becomes the lamp current command value I<sub>la</sub>\* as it is, in which case constant-current control for making the lamp current constant regardless of the lamp voltage is conducted; in the embodiment, however, the component of the detection voltage V<sub>la</sub> responsive  
25 to the lamp voltage is also fed back and is added, so that the

output characteristic of increasing the lamp current in response to the lamp voltage as shown in FIG. 1 (b) can be realized comparatively easily. Although not shown in FIG. 3, the lamp voltage is also detected in a lamp light determination circuit and an anomaly protection circuit and thus they can also be used as the circuit, needless to say.

[0027] FIGS. 4 (a) and 4 (b) show measurement data provided when dimming control of a high-pressure discharge lamp is actually performed using the invention; FIG. 4 (a) represents the lamp power  $W$  relative to the lamp voltage  $V$  at the ratio with the value at the rated lighting time of the lamp being 100% for both the voltage and the power. Lines indicated by dim1, dim2, dim3, and dim4 indicate the output characteristic of the lighting device measured as a variable resistor is connected in place of a high-pressure discharge lamp at one dimming level, and correspond to BC1 described with reference to FIG. 1 (a). LC indicates the lamp characteristic when the lamp is actually lighted in place of the variable resistor, and corresponds to LC in FIG. 1 (a). Breaking off of the solid line LC at the dimmer lower limit indicates going out or occurrence of fierce flicker. It is seen in the figure that going out does not occur and the lamp is stably lighted even in an area where the lamp voltage rapidly rises.

[0028] FIG. 4 (b) represents the lamp current  $I$  relative to the lamp voltage  $V$  at the ratio with the value at the rated

lighting time of the lamp being 100% for both the voltage and the current. Lines indicated by dim1, dim2, dim3, and dim4 indicate the output characteristic of the lighting device measured as a variable resistor is connected in place of a high-pressure discharge lamp at one dimming level, and correspond to BC1 described with reference to FIG. 1 (b). LC indicates the lamp characteristic when the lamp is actually lighted in place of the variable resistor, and corresponds to LC in FIG. 1 (b). It is seen in FIG. 4 (b) that it shows the same characteristic as the characteristic shown in FIG. 1 (b) wherein the output current of the lighting device at one dimming level grows in response to an increase in the lamp voltage.

[0029] For comparison, an experiment was conducted in a similar manner in constant-current control with addition of none of the resistors R3 and R4 and the capacitor C3 in FIG. 3. FIGS 5 (a) and 5 (b) show the result. Symbols in FIGS 5 (a) and 5 (b) are similar to those in FIGS 4 (a) and 4 (b) and therefore will not be discussed again. As compared with FIG. 4, it is obviously seen that the dimming lower limit of LC at the lamp lighting time does not lower as that in FIG. 4. That is, it is obviously seen that dimming is possible up to about 20(%) of the rating of lamp power and up to about 16(%) of the rating of lamp current in the invention in FIG. 4, whereas dimming in the constant-current control in FIG. 5 does not reach them.



[0030] According to the embodiment, low luminous lighting can be stably executed in a wider range as compared with the constant-current control. The ratio of (change amount of lamp current/ change amount of lamp voltage) is made roughly  
5 constant, whereby control can be facilitated and can be realized by a simple control circuit.

[0031] (Second embodiment)

FIGS. 6 (a) and (b) show the operation characteristics of a discharge lamp lighting device according to a second  
10 embodiment of the invention. In the figures, LC indicates the lamp characteristic and lines indicated by BC1, BC1', and BC1" indicate the output characteristic of the lighting device. FIG. 6 (a) differs from FIG. 1 (a) in that the gradient of the output characteristic of the lighting device is increased as  
15 dimming becomes deeper. Such control is performed, whereby the output characteristic of the lighting device and the lamp characteristic cross more orthogonally even in a low luminous area where the lamp voltage rapidly changes, so that it is made possible to maintain the operation point reliably. Although  
20 a circuit is not shown, for example, detection value  $V_{la}$  detected by a lamp voltage detection circuit may be squared for use, etc., and it can be accomplished comparatively easily.

[0032] FIG. 6 (b) is a graph provided by converting the vertical axis in FIG. 6 (a) into lamp current  $I$  and shows those  
25 corresponding to the lamp characteristic LC and the output

characteristic of the lighting device BC1, BC1', and BC1" in FIG. 6 (a). It is also seen in FIG. 6 (b) that when dimming is deepened, the output characteristic of the lighting device and the lamp characteristic cross more orthogonally.

5           According to the embodiment, if dimming is deepened, the operation point is provided reliably, so that low luminous lighting can be stably executed in a wider range.

[0033]           (Third embodiment)

FIGS. 7 (a) and (b) show the operation characteristics  
10 of a discharge lamp lighting device according to a third embodiment of the invention. FIG. 7 (a) differs from FIG. 1 (a) in that constant-current control is adopted for the output characteristic of the lighting device in the lamp voltage range of 0 to  $V_{th}$ . The same description as in the first embodiment  
15 applies to an area where the lamp voltage is larger than  $V_{th}$ , namely, an area where the lamp voltage is larger than point A of the output characteristic of the lighting device.

[0034]           Generally, after a high-pressure discharge lamp is started by a starter circuit like an igniter, lamp voltage  
20 gradually grows from the vicinity of 0 (V). Output characteristic is provided reliably from voltage 0 (V), so that the lamp operation point shifts on BC1 in FIG. 7 (a) and, for example, dimming starting can be executed. Although not shown in the figure, a measure of current needs to be allowed to flow  
25 for several 10 seconds just after the lamp is started and

therefore FIG. 7 (a) shows the characteristic after the time.

[0035] FIG. 7 (b) is a graph provided by converting the vertical axis in FIG. 7 (a) into lamp current  $I$  and shows those corresponding to the lamp characteristic LC and the output characteristic of the lighting device BC1 in FIG. 7 (a). The lamp current is controlled constantly in the lamp voltage range of 0 to  $V_{th}$  and when the lamp voltage becomes larger than  $V_{th}$ , the lamp current command value is also increased in response to an increase in the lamp voltage.

10 [0036] FIG. 8 shows the circuit configuration of the embodiment. FIG. 8 differs from FIG. 2 in that a lamp voltage detection circuit 55 for detecting the voltage across a high-pressure discharge lamp DL and a circuit made up of a comparator COMP1 for making a comparison between a detection value  $V_{la}$  of the detection circuit 55 and a DC voltage  $V_{th}$  and a switch SW for switching a lamp current command value  $I_{la}^*$  between  $V_{bc1}$  and  $V_{bc2}$  depending on output of the comparator COMP1 are added to a control circuit 5 and that the output voltage of a variable voltage source  $V_{dim}$  is made variable  
15 according to a signal from a dimmer 2, whereby the value of  $V_{bc2}$  can be adjusted. Using the circuit, a circuit wherein characteristic changes based on the lamp voltage  $V_{th}$  as shown in FIGS. 7 (a) and 7 (b) can be configured easily. To use the configuration illustrated in FIG. 3 as a lamp current command  
20 value computation circuit 52, a circuit made up of resistors

R3 and R4 and a capacitor C3 can also be used as the lamp voltage detection circuit 55.

[0037] In the time period during which the lamp voltage detection signal  $V_{la}$  is smaller than predetermined DC voltage  $V_{th}$ , the comparator COMP1 outputs low, causing the switch SW to switch into  $V_{bc2}$ . When the switch SW switches into  $V_{bc2}$ , the lamp current command value  $I_{la}^*$  becomes  $V_{dim}$  set arbitrarily by a signal from the dimmer 2, thus resulting in constant-current control responsive to each dimming level.

10 After the lamp is started, the lamp voltage gradually increases and when the lamp voltage detection signal  $V_{la}$  exceeds the predetermined DC voltage  $V_{th}$ , the comparator COMP1 outputs high, causing the switch SW to switch into  $V_{bc1}$ . In this case, similar control to that previously described in the first

15 embodiment is performed, so that low luminous lighting can be stably executed.

[0038] According to the embodiment, after start, the output characteristic of the lighting device is provided from lamp voltage 0 V to the voltage at the operation point, so that

20 dimming starting can be executed reliably with low luminous flux, for example. It can be implemented as a simple control circuit.

[0039] (Fourth embodiment)

FIGS. 9 (a) and (b) show the operation characteristics

25 of a discharge lamp lighting device according to a fourth

embodiment of the invention. The embodiment differs from the third embodiment in that the value of the switch point  $V_{th}$  of the control operation in the third embodiment is increased as dimming becomes deeper.

5 [0040] A description is given below with FIG. 9 (a): In the figure, output characteristic of the lighting device BC1 passing through points A and B is the same as the characteristic shown in the third embodiment. When the lamp voltage reaches  $V_{th1}$ , the control operation switches at the point A in the  
10 figure and the lamp is lighted at the intersection point of the output characteristic of the lighting device BC1 and lamp characteristic LC. FIG. 9 (b) is a graph provided by converting the vertical axis in FIG. 9 (a) into lamp current  $I$  and shows those corresponding to the lamp characteristic LC and the  
15 output characteristic of the lighting device BC1, BC1', and BC1'' in FIG. 9 (a).

[0041] Next, if an attempt is made to deepen dimming with the circuit shown in the third embodiment intact, the value of  $V_{th1}$  remains unchanged and thus the output characteristic  
20 of the lighting device shifts from BC1 described above to BC1'. However, in an area where the lamp voltage is larger than  $V_{th1}$ , the characteristics of BC1 and BC1' are characteristics close to orthogonality with the lamp characteristic LC and thus the operation point change amount is small and thus brightness  
25 change is hard to see although lighting maintenance is good.

If the gradient of the line from point A' to point B' is made gentle to provide a brightness difference from BC1, a brightness difference is provided, in which case going out easily occurs.

5 [0042] Then, to execute deeper dimming from the output characteristic of the lighting device BC1, the switch point is changed from  $V_{th1}$  to  $V_{th2}$ , whereby the output characteristic of the lighting device becomes as BC1" and the brightness difference can be increased with the same gradient intact as  
10 compared with BC1'. Therefore, the value of the switch point  $V_{th}$  is changed arbitrarily in response to the lamp voltage, so that fine adjustment of the brightness at the dimming time is made possible. If the light output difference is too large with respect to the dimming level, control may be performed  
15 in the direction of decreasing the switch point  $V_{th}$  in response to the lamp voltage.

[0043] FIG. 10 shows the circuit configuration of the embodiment. FIG. 10 differs from FIG. 8 in that detection value  $V_{la}$  of a lamp voltage detection circuit 55 controls the DC  
20 voltage  $V_{th}$  determining the voltage at the switch point of the control operation. The circuit is thus configured, whereby the value of  $V_{th}$  also grows as the lamp voltage increases, so that the output characteristic of the lighting device like BC1" in FIG. 9 (a), (b) can be obtained.

25 [0044]

The circuit may be configured so as to perform variable control of the voltage of DC voltage source  $V_{th}$  in response to the magnitude of a dimming signal as shown in FIG. 11. Variable control of the magnitude of the DC voltage  $V_{th}$  is performed in response to the magnitude of the dimming signal, for example, in such a manner that if the dimming signal has a magnitude of passing through the point A in FIG. 9 (a), (b), the switch point is set to  $V_{th1}$  and if the dimming signal has a magnitude of passing through a point A" in FIG. 9 (a), (b), the switch point is set to  $V_{th2}$ .

[0045] According to the embodiment, the voltage at the switch point between constant-current control and the control operation of low luminous lighting according to the invention is changed in response to the depth of dimming, so that brightness adjustment in a low luminous area can be made easily.

[0046] (Fifth embodiment)

FIG. 12 shows the operation characteristics of a discharge lamp lighting device according to a fifth embodiment of the invention. The embodiment is an embodiment for reliably executing low luminous lighting even in a state in which a lamp has been lighted for a long term and is at the last stage of the life, for example.

[0047] In FIG. 12, lamp characteristic LC and output characteristic of the lighting device BC are similar to those described in the third and fourth embodiments. When the lamp

is lighted for a long term, the lamp voltage becomes high and thus the lamp characteristic LC shifts to the right and before long, becomes a characteristic like LC' indicated by the dotted line. Therefore, to provide the same lamp power as that at the operation point of the lamp indicated by the intersection point of the lamp characteristic LC and the output characteristic of the lighting device BC1 if the lamp is lighted for a long term, the dimming level may be lowered in response to the lighting time and the value of a switch point Vth1 may also be increased as in the fourth embodiment, and the switch point with the value increased becomes Vth3. The output characteristic of the lighting device to switch to at Vth3 is BC1' indicated by the alternate long and short dash line, and the lamp power at the intersection point of LC' and BC1' can be set to almost the same as the lamp power at the intersection point of LC and BC1 described above.

[0048] FIG. 13 shows the circuit configuration to accomplish the characteristic in FIG. 12. FIG. 13 differs from FIG. 10 in that instead of performing variable control of the DC voltage source Vth according to the lamp voltage detection value in FIG. 10, the output value of a DC voltage source Vth is gradually increased with the passage of lighting time with a lighting time integrating timer 56 and that the output value of a DC voltage source Vdim determining the gradient from a point A to a point A' in FIG. 12 is also changed according to



an output signal of the lighting time integrating timer 56.  
The output value of the DC voltage source  $V_{dim}$  is decreased  
with the passage of the lighting time. Other points are the  
same as those in FIG. 10 and therefore will not be discussed  
5 again.

[0049] If the lamp is lighted for a long term like several  
1000 hours, illuminance tends to lowers as a whole because of  
blackening of an arc tube or the like and thus in fact it is  
desirable that the operation point after lighting for a long  
10 term should be set a little larger than that at the initial  
time. That is, the lamp power in the vicinity of the dimming  
lower limit is set larger than that at the initial time for  
variation of the lamp with time, so that illuminance at the  
same degree as that at the initial time of lighting the lamp  
15 can be obtained.

[0050] According to the embodiment described so far, the  
output characteristic of the lighting device can be  
accomplished comparatively easily because of the  
characteristic that the lamp power and the lamp current  
20 increase relative to the lamp voltage; for example, even the  
circuit as shown in FIG. 3 can handle simply by changing a  
constant.

[0051] As described above, according to the embodiment,  
the lamp power in the vicinity of the dimming lower limit can  
25 be set to power at the same degree as that at the initial time

for variation of the lamp with time. The lamp power in the vicinity of the dimming lower limit is set larger than that at the initial time for variation of the lamp with time, so that illuminance at the same degree as that at the initial time  
5 of lighting the lamp can be obtained.

[0052] (Sixth embodiment)

FIGS. 14 (a) and (b) show the operation characteristics of a discharge lamp lighting device according to a sixth embodiment of the invention. The embodiment performs  
10 continuous dimming control from rated lighting to the dimming lower limit of low luminous flux and suppresses an unstable phenomenon occurring at the switching time of different control between constant-power control and constant-current control, for example.

[0053] A detailed description is given below: In FIG. 14 (a), the output characteristic at a related lighting point CP1 of intersection points CP1, CP2, ..., CP6 of lamp characteristic LC indicated by the solid line and output characteristic of the lighting device indicated by dotted lines  
20 is BC1 and the output characteristic changes as BC2, BC3, ..., BC6 in response to deepening of dimming. FIG. 14 (b) is a graph corresponding to FIG. 14 (a) with the lamp current on the vertical axis; points indicated by CP1, CP2, ..., CP6 indicate the intersection points of the lamp characteristic LC and the  
25 output characteristic of the lighting device BC1, BC2, ...,

BC6 in FIG. 14 (a), so-called lamp operation points.

[0054] The BC1, BC2 output characteristic at the operation point CP1, CP2 is conventional constant-power control and is maintained almost at constant power in the vicinity of the operation point if the lamp voltage changes.

The BC4 output characteristic at the operation point CP4 is constant-current control as shown in the related art example and is maintained almost at constant current in the vicinity of the operation point if the lamp voltage changes. The BC3

output characteristic at the operation point CP3 is intermediate control of the constant-power control and the constant-current control described above and the lamp power increases and the lamp current decreases in response to an increase in the lamp voltage. The BC5, BC6 output

characteristic at the operation point CP5, CP6 is control of increasing the lamp current with an increase in the lamp voltage as described in the embodiments. These types of control are performed continuously in response to the dimming level, whereby smoother dimming can be realized from the rated lighting to the dimming lower limit. Since the conventional constant-power control is applied in the vicinity of the rated lighting, when the lamp voltage fluctuates, excessive power is not added to the lighting device.

[0055] FIG. 15 is a graph indicating lamp power on the horizontal axis and lamp current change amount  $\Delta I$ /lamp voltage

change amount  $\Delta V$  on the vertical axis and corresponds to the gradient at each operation point in FIG. 14 (b). The gradient becomes a negative value in the CP1 vicinity implementing constant-power control and is gradually changed to 0 and constant-current control is accomplished at the operation point CP4 where  $\Delta I/\Delta V$  becomes 0. To maintain low luminous lighting from the point, the gradient is set to a positive value at the CP5, CP6 operation point.

[0056] FIG. 16 shows an example of an almost similar characteristic to that in FIG. 14 (b). This is characterized by the fact that the output characteristic of the lighting device becomes symmetrical with lamp current  $I_l$  as the boundary. In FIG. 16, the operation points are indicated by white circles as in FIG. 14 (b). Such a symmetrical characteristic is provided, whereby when the output characteristic is put into a data table of a microcontroller, etc., for example, the symmetry can be used to about halve the data amount.

[0057] FIG. 17 shows a circuit example for accomplishing the output characteristic in FIG. 14 (b). The output characteristic in FIG. 14 (b) is previously retained in a data table of a microcontroller, etc., and a lamp current command value  $I_{la}^*$  is determined by a lamp voltage detection value  $V_{la}$  and a dimming signal from a dimmer. In the figure, if a value of  $V_{la1}$  is detected as the lamp voltage and the dimming signal from the dimmer is a level of Dim5,  $I(\text{Dim5})$  is selected as the

lamp current command value from characteristic drawing of the data table and is output as the command value  $I_{la}^*$ . If all characteristics  $Dim1, Dim2, \dots, Dim6$  from the rating to deep dimming are thus put into the data table, a switching circuit at  $V_{th}$  as used with the embodiments described above becomes unnecessary and the control circuit can be simplified.

[0058] According to the embodiment, smooth and continuous control can be executed in a wide range of the rated lighting to the dimming lower limit using the conventional constant-power control, the intermediate control of the constant-power control and the constant-current control, the constant-current control, and the low luminous lighting control described so far in combination. The data table of the microcontroller is referenced, whereby the operation switching circuit responsive to the lamp voltage, etc., becomes unnecessary and the circuit configuration can be simplified.

[0059] In the embodiment, the circuit example of using a step-up chopper circuit, a step-down chopper circuit, and an inverter of full bridge type in combination is shown in FIG.

3 as the configuration of the main circuit, but the invention is not limited to it. For example, a circuit as shown in FIG. 18, 19, or 20 may be adopted and the waveform of the lamp current need not be a rectangular wave at about several 100 Hz and may be a high-frequency sine wave, etc., needless to say. It is essential that the control be control for providing the

characteristic as shown in FIG. 1 (a), (b) as the output characteristic of the lighting device.

[0060] In a circuit example in FIG. 18, a commercial AC power supply  $V_s$  is rectified by a full-wave rectifier made up of diodes D1 to D4 and is converted into a DV voltage by a step-up chopper circuit made up of an inductor L1, a switching element Q1, a diode D5, and a smoothing capacitor C1, the DV voltage is converted into an AC voltage by a full-bridge inverter circuit made up of switching elements Q3, Q4, Q5, and Q6, and the AC voltage is supplied through an igniter IG to a high-pressure discharge lamp DL.

[0061] A circuit example in FIG. 19 uses a half-bridge inverter circuit to which a series circuit of electrolytic capacitors C1 and C2 is connected in place of the series circuit of the switching elements Q5 and Q6 in the circuit example in FIG. 18. An igniter IG is made up of a step-up pulse transformer and a pulse generation circuit and at the starting time, the pulse generation circuit generates a pulse voltage, whereby a high-voltage pulse is applied from the secondary side of the pulse transformer to a high-pressure discharge lamp DL. The DC voltage of the electrolytic capacitors C1 and C2 is subjected to variable control as turning on/off of the switching element Q1 is controlled. The configuration of the DC-DC converter is not limited to the step-up chopper shown in the figure and any desired circuit configuration of a step-down chopper, a

step-up and step-down chopper (inversion-type chopper), a flyback DC-DC converter, or the like can be used, needless to say.

[0062] In a circuit example in FIG. 20, in place of igniter

5 IG of a separate circuit, a resonance circuit made up of an inductance L2 and a capacitor C3 is connected to both ends of a switching element Q4 through a coupling capacitor C2 and at the starting time, switching elements Q3 and Q4 are turned on and off alternately in the vicinity of the resonance frequency, whereby a starting high voltage is generated and at the lighting  
10 time, the switching elements Q3 and Q4 are turned on and off alternately at the frequency responsive to the lamp power, whereby continuous output control can be executed in a wide range of the rated lighting to the dimming lower limit.

15 [0063] The high-pressure discharge lamp lighting device described so far is built in a lighting fixture, for example, as shown in FIG. 21 or a lighting system for controlling the lighting fixtures for use. In the figure, numeral 8 denotes an electronic ballast, numeral 9 denotes lamp wiring, and  
20 numeral 10 denotes a reflecting plate. Here, a down light is illustrated as the lighting fixture, but the high-pressure discharge lamp lighting device can also be applied to a spot light or any other desired lighting fixture, needless to say.

[0064] While the invention has been described in detail  
25 with reference to the specific embodiments, it will be obvious

to those skilled in the art that various changes and modifications can be made without departing from the spirit and the scope of the invention.

This application is based on Japanese Patent Application  
5 (No. 2004-091111) filed on March 26, 2004, which is incorporated herein by reference.

#### Industrial Applicability

[0065] According to the invention as claimed in claim 1,  
low luminous lighting can be stably executed in a wider range  
10 as compared with the constant-current control in the related art.

According to the invention as claimed in claim 2, change amount of lamp current/change amount of lamp voltage is made constant, whereby control can be facilitated.

15 According to the invention as claimed in claim 3, if dimming is deepened, the operation point is provided reliably, so that low luminous lighting can be stably executed in a wider range.

According to the invention as claimed in claim 4, after  
20 start, the output characteristic of the lighting device is provided from lamp voltage 0 V to the voltage at the operation point, so that low luminous dimming starting can be executed reliably, for example.

According to the invention as claimed in claim 5, the  
25 value of the lamp voltage at the switch point between



constant-current control and the operation according to the invention is changed in response to dimming, so that brightness adjustment in a low luminous area can be made easily.

[0066] According to the invention as claimed in claim 6,

5 the lamp power in the vicinity of the dimming lower limit can be set to power at the same degree as that at the initial time for variation of the lamp with time.

According to the invention as claimed in claim 7, smooth and continuous control can be executed in a wide range of the  
10 rated lighting to the dimming lower limit using the constant-power control, the intermediate control of the constant-power control and the constant-current control, the constant-current control, and the low luminous lighting time control of the invention in combination.

15 According to the invention as claimed in claim 8, 9, 10, control can be facilitated and can be realized by a simple control circuit.

According to the invention as claimed in claim 11, the data table of the microcontroller is referenced, whereby the  
20 control operation switching circuit responsive to the lamp voltage, etc., becomes unnecessary and the circuit can be simplified.

According to the invention as claimed in claim 12, the amount of data to be stored in the data table of the  
25 microcontroller can be lessened.

According to the invention as claimed in claim 13, a lighting fixture that can be dimmed up to a lower level than that in the related arts can be provided.